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Effect of a sensory diet smartphone application on the symptoms of children with attention deficit hyperactivity disorder (ADHD): A feasibility study

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ABSTRACT

Introduction: Sensory integration and sensory diet can improve the symptoms of children with attention deficit/hyperactivity disorder (ADHD). This feasibility study aimed to evaluate the effect of using a sensory diet smartphone application by mothers on the main symptoms of their children with ADHD, including hyperactivity, attention deficit, and impulsivity.

Methods: We conducted a need assessment study with the collaboration of 15 occupational therapists, developed an Android-based prototype, and evaluated it in terms of usability with the participation of 12 available mothers of children with ADHD. 12 other selected children were divided into control and experimental groups. At first, these children were evaluated using the hyperactivity subscale of the fourth version of the Pediatric Symptoms Questionnaire, and after two months of using the application by the mothers of the children in the experimental group, both groups were re-evaluated using the same questionnaire. We compared the mean score of this questionnaire before and after the mothers' use of the application.

Results: The application included 105 sensory diet exercises presented in animated format with accompanying text explanations. According to mothers' feedback, the usability of the application was rated at a high level with an average score of 8.35 out of 9. In the experimental group, attention deficit significantly improved compared to the pre-intervention stage (Mean $\pm$ SD = 13.67 $\pm$ 6.86 vs. 22 $\pm$ 6.13, P-value$<$0.0001) and compared to the control group after the intervention (P-value = 0.048). Additionally, after the intervention, the experimental group showed significant improvements in impulsivity (mean difference = $-$1.33) and hyperactivity (mean difference = $-$4.67) compared to the pre-intervention (P-value = 0.025 and 0.034, respectively). However, these improvements were not statistically significant when compared to the control group (P-value = 0.937 and 0.58, respectively).

Conclusion: The findings suggest that sensory diet smartphone applications have the potential to help alleviate symptoms related to attention deficit in children with ADHD.

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1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is recognized as a neurodevelopmental disorder according to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM 5) [1,2]. It is estimated that approximately 8–10% of children in the United States have ADHD [3].

The brain receives incoming messages from the body's sensory organs and sends outgoing messages to the muscles [4,5]. While each sense functions independently, their coordination allows for appropriate adaptive behaviors and functioning. Difficulties with sensory integration can hinder children's ability to engage in activities that require it. Children with ADHD commonly experience challenges in this regard [6]. Sensory deficit refers to difficulties with one or multiple senses. The sensory over-responsivity, sensory under-responsivity, sensory discrimination problems, and sensory seeking are the different types of sensory deficit [7].

The three main symptoms associated with ADHD are attention deficit, hyperactivity, and impulsivity. Children with ADHD often exhibit constant movement and climbing, even when expected to sit still. They tend to be highly active, talkative, absent-minded, and forgetful. Difficulties in initiating and completing tasks, as well as challenges in social relationships, are also common. Listening to others, keeping track of belongings, and taking turns can be particularly challenging for them. These symptoms frequently lead to various difficulties within educational settings [8]. Impulsivity is closely related to attention deficit and hyperactivity in the context of ADHD. According to DSM 5, impulsivity refers to the tendency to react immediately to stimuli without considering the potential consequences. It involves decreased attention, increased activity levels, and deficits in planning. The Barat Impulsiveness Scale assesses three factors to measure impulsivity: increased motor activity, decreased attention, and decreased planning [9].

Children with ADHD may experience difficulties in receiving and processing sensory information, leading to challenges in appropriately responding to the inputs [10]. These difficulties can impact their functioning at home, school, and in social situations [11]. In addition to pharmacological treatments, there are various non-pharmacological approaches available for managing ADHD. One such approach is sensory integration therapy, which aims to improve the central nervous system's ability to process information. Sensory integration therapy improves the coordination and interpretation of sensory inputs by affecting the vestibular systems and the upper-level brain functions, resulting in good adaptive functioning [12].

Sensory integration refers to the neural process that allows the body to efficiently and effectively interact with the environment by utilizing sensory information received from both the body and the environment [13]. A sensory diet, on the other hand, is a predefined program of sensory inputs that includes the vestibular sense (movement), the proprioception (muscle and joint information), tactile sense, hearing, taste, and smell. These sensory inputs help children maintain focused and organized attention. Just as a diet is tailored to meet a person's nutritional needs, a sensory diet is designed to address a child's specific sensory needs by providing the appropriate combination of sensory experiences in the right amounts.

The sensory diet is designed according to the individual needs to keep the child awake and calm [14]. Sensory integration and sensory diet therapy is a specialized treatment in the field of occupational therapy [15]. Research by Sahoo demonstrated that a sensory diet can improve executive functions in children with ADHD [11]. Another study found that sensory integration therapy was effective in addressing all three ADHD symptoms: attention deficit, hyperactivity, and impulsivity [8]. Furthermore, Lee et al. [16] discovered that sensory integration therapy can positively impact the self-esteem and social skills of children with ADHD.

Mobile health is increasingly used in the treatment of children with ADHD. A recent systematic review examined various ADHD-related applications. These applications encompassed areas such as music therapy, psychotherapy training, organizational skill training, monitoring ADHD medications, neurofeedback training, cognitive training, and hypnosis [17]. Furthermore, several studies have demonstrated the effectiveness of software and applications in both diagnosing and treating ADHD [18,19]. This highlights the emerging trend of utilizing technology to enhance ADHD interventions and support the overall management of the condition.

To our knowledge, there is currently no specific smartphone application that has been suggested for sensory diet exercises. Furthermore, sensory integration therapy depends on parents to effectively implement the prescribed exercises, and teaching parents about this therapy is recognized as one of the five key educational needs for parents of children with sensory integration disorders [20]. Therefore, this feasibility study aimed to evaluate the effect of a smartphone application developed by researchers on alleviating the symptoms experienced by children with ADHD.

2. Materials and methods

2.1. Development of the application

We designed a questionnaire to gather insights from occupational therapists regarding the features of the application and exercises. The exercises included in the questionnaire were sourced from previously published materials [21–23]. Subsequently, we invited all fifteen faculty members from the Department of Occupational Therapy at Iran, Tehran, Shahid Beheshti, Welfare Sciences, and Isfahan Universities of Medical Sciences to participate in a needs assessment by completing the questionnaire. The respondents were asked to indicate whether each feature or exercise was necessary or not necessary using a two-choice format. Based on the feedback received, we developed the application incorporating the features and exercises that were deemed necessary by more than 75% of the respondents.

We developed the application in the Android Studio development environment. It included a total of 105 sensory diet exercises that were presented through animated images, accompanied by detailed explanations in Persian. To create the content, we enlisted the help of a healthy child and her mother who performed all the exercises while being filmed. For example, ball therapy involved various movements such as linear movement, clockwise movement, counterclockwise movement, etc. We obtained the written consent form

from the child's parents, as well as the child's verbal consent. One occupational therapist (second author) reviewed and provided feedback during the development of the application.

In addition to the exercises, the final application provides educational content covering various aspects of ADHD. This includes a definition of ADHD, its signs, symptoms, and classification of the disease. The application also provides information on sensory integration therapy and offers behavioral advice for parents.

Furthermore, the application incorporates several additional features to enhance user experience. Users can set reminders to ensure regular exercise sessions, calculate exercise duration, and customize the time allocated for each exercise. The app also allows users to track their exercise progress by recording the dates of completed exercises. Additionally, users have the option to personalize the app's font and text size according to their preferences. The application also enables users to store personal data for reference and analysis. For a more detailed understanding of the exercises, the supplementary file contains descriptions of some exercises along with accompanying animated gifs. These resources serve as visual aids to assist users in performing the exercises correctly.

Figs. 1–4 illustrate various features of the application. As sensory diet requirements can differ from person to person, the

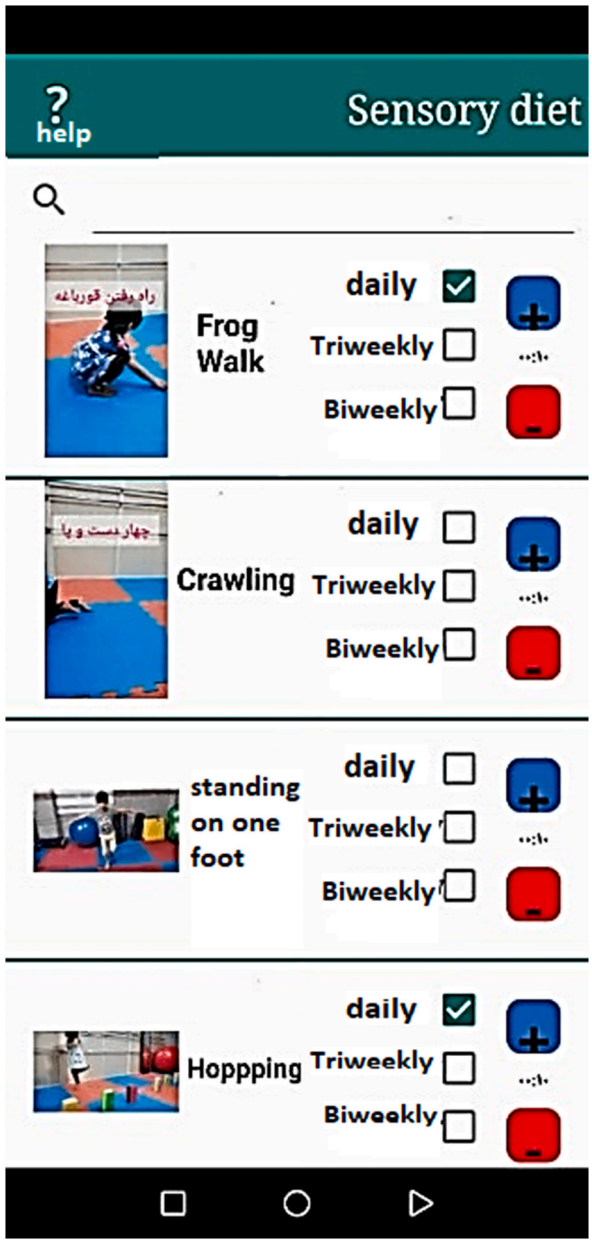

Fig. 1. Scheduling the exercises by therapist (therapist can order the exercises, and the duration using + or – buttons, and frequency of each exercise (daily, two or three days a week)).

occupational therapist can customize and establish a sensory diet based on the child's specific needs. They can schedule the exercises by specifying the day of the week, duration, and frequency of each exercise (Fig. 1). Subsequently, parents can access their child's scheduled diet, which is organized on a weekly basis. Each day of the week, the child is presented with a list of exercises assigned for that particular day (Fig. 2). Clicking on an exercise initiates an animated image accompanied by educational text to guide the child through the exercise (Fig. 3). The "Start" button activates a timer, and upon completion of the designated time, users are notified and can proceed to the next exercise. The completed exercises, along with the date, are recorded in the user's history. Additionally, parents have the option to set reminders, adjust the font and text size according to their preferences (Fig. 4), and access educational content related to ADHD within the application.

2.2. Usability evaluation

We used the standard QUIS questionnaire version 5.5 to evaluate the usability and user satisfaction of our application (Supplementary file). The reliability and validity of this tool have been previously reported [24,25]. We conveniently selected 12 mothers of children with ADHD from Valiasr Charity Medical Center, Isfahan, Iran. Inclusion criteria consisted of a confirmed diagnosis of ADHD by a specialist, absence of comorbidities in the child, mother's consent to participate, and proficiency in using an Android-based smartphone. The mothers were instructed to use the application for two weeks and subsequently complete the questionnaire. To analyze the data, we calculated the mean score for each dimension of the QUIS.

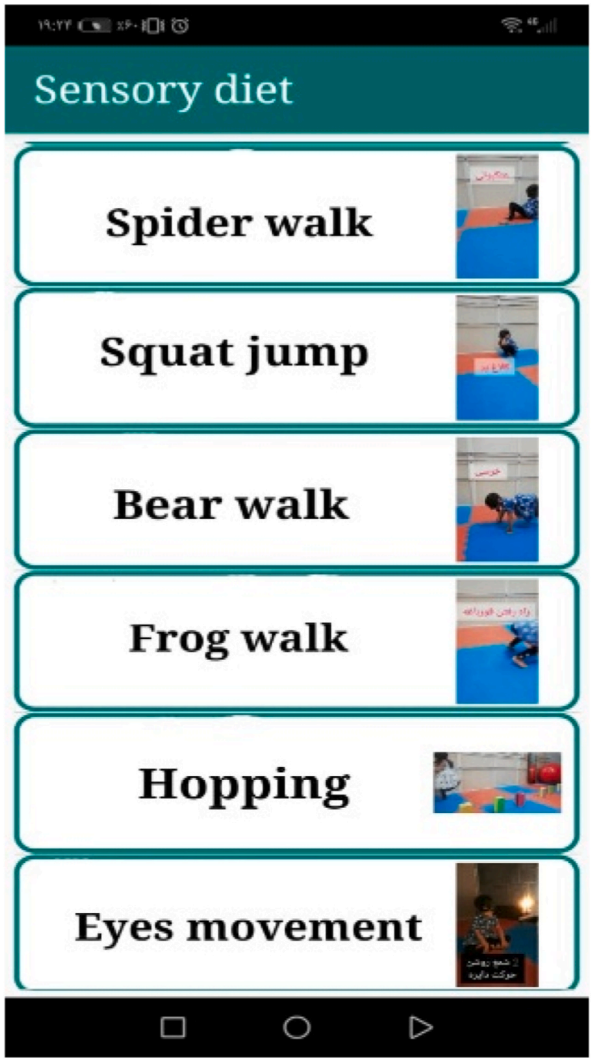

Fig. 2. List of ordered exercises (Parent can select each one to see the further details).

Fig. 3. Exercise explanation (parents can watch and read the exercise explanation, start or restart each exercise and navigate between previous and next ordered exercises).

2.3. Evaluation of the effect of the application

2.3.1. Samples

The study included a sample of 12 children who were conveniently selected from Valiasr Charity Clinic in Isfahan. Inclusion criteria were similar to those used for the usability evaluation. However, we recruited a different group of patients and mothers. The patients were randomly assigned to either the control group (one girl and five boys) or the experimental group (four boys and two girls). These children were managed by three occupational therapists, each with 2–5 years of working experience. Each therapist was responsible for four patients in both groups.

2.3.2. Sensory diet prescription

All occupational therapists were blinded to the group assignment. They evaluated their patients according to established routines and protocols. They prescribed specific exercises and documented the sensory diet in the patients' medical records. While the application facilitated the ordering of sensory diet exercises by occupational therapists, a trained researcher (first author) reviewed the medical records of children in the experimental group and extracted the prescribed exercises. Subsequently, the researcher entered the diet exercises into the application for each child. This process was implemented to maintain the blinding of the occupational therapists.

2.3.3. Data collection

The Child Symptom Inventory (CSI-3) is a screening tool based on DSM-III that is used to assess various behavioral disorders. The ADHD sub-test of the CSI-3 has reported sensitivity and validity rates of 0.77 and 76%, respectively [26].

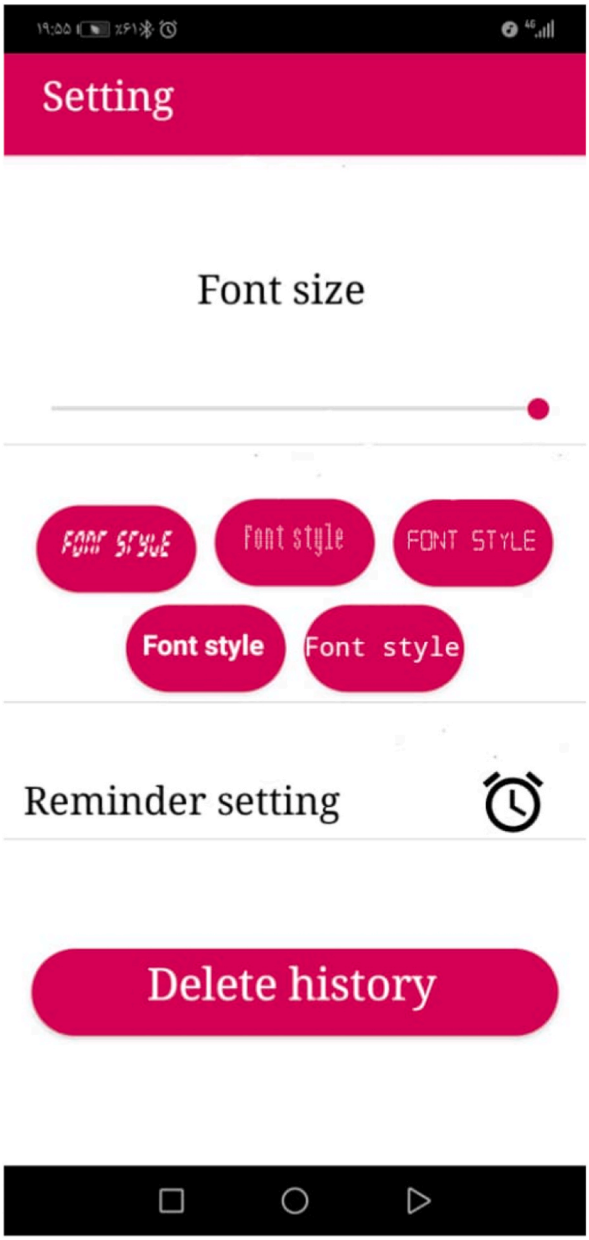

Fig. 4. Setting page (parents can set alarm for exercises, change the font size and style and delete the history).

A revised version of the CSI-3, known as the CSI-4, is based on the DSM-IV criteria. The CSI-4 consists of two forms: one for parents and another for teachers [27,28]. This subscale includes 18 items, with 9 items assessing attention deficit, 6 items assessing hyperactivity, and 3 items assessing impulsivity. Several studies demonstrated that both versions of the ADHD symptom category of CSI-4 had satisfactory test-retest reliability, concurrent validity with other behavior rating scales, and criterion validity for children aged 3–18 years [27–33]. For example, in one study, the parent version of the ADHD subtest showed high internal consistency reliabilities (Cronbach's α) for CSI-4 symptom severity, with values of 0.92 for ADHD inattention, 0.91 for ADHD hyperactivity-impulsivity, and 0.91 for the combined 18-item ADHD scale. Test-retest reliabilities over 1 month were 0.75, 0.84, and 0.79, respectively, and similar levels of reliability were observed at 2 and 4 months [34].

We utilized the Persian translation of the parent version of the CSI-4 ADHD subtest to assess attention deficit, hyperactivity, and impulsivity. Previous studies have demonstrated the reliability and validity of the Persian version [35,36]. In this study, mothers answered the questions based on their child's symptoms, condition, and behavior. They assessed the symptoms using a 4-point scoring scale (0 for "never", 1 for "sometimes", 2 for "often", and 3 for "very often") [26]. The questionnaire can be found in the Supplementary file.

Before using the application by the mothers, all children were evaluated using this test. Subsequently, we installed the application on the mothers' smartphones in the experimental group. Mothers were instructed to use the application and perform the prescribed exercises for their children according to the designated schedule over a period of two months. After the two-month intervention period, both the experimental and control groups underwent a post-evaluation using the same test.

It should be noted that during the two months, both groups received routine occupational therapy. The treatment offered to both groups in occupational therapy sessions was a combination of different methods to suit the needs of each child.

2.3.4. Data analysis

We calculated and compared the mean score and mean differences for the three symptoms. We initially assessed the data distribution of the pre-test and post-test scores for each symptom using the Kolmogorov-Smirnov test. Based on the results, we applied either parametric or non-parametric statistical tests as appropriate. To conduct these analyses, we utilized SPSS software version 22. We considered a p-value less than 0.05 to indicate a statistically significant difference.

2.3.5. Ethical considerations

This study received ethics approval from the Research Ethics Committee of the Iran University of Medical Sciences (IR.IUMS.REC.1397.1104). Furthermore, participation was completely voluntary and participants in the control group received the application after the end of the study. Informed consent was obtained from all participants before their involvement in the study. Additionally, for the filming of exercises, we obtained oral consent from the child and written consent from their parents.

3. Results

The majority of participant mothers fell within the age range of 36–40 (41.7%) followed by 25–30 and 31–35 years old (25% each). A significant portion of them possessed a high school diploma (58.3%), while others held a bachelor's degree (33.3%). The usability evaluation of the application revealed that users gave it an overall mean score of 8.35 (out of 9) and considered it highly useable. Furthermore, other usability dimensions received commendable mean scores, including Learning (8.7 ± 0.58), Screen (8.6 ± 0.61), Terminology and Application Information (8.5 ± 0.58), Application Capabilities (8.2 ± 0.45), and Reaction to the Application (7.9 ± 0.64).

In the experimental group, four children were five years old and two children were six years old. Four boys and two girls participated in the experimental group. There were no significant differences between the two groups in terms of age and sex of children (Table 1). As shown in Table 2, there were no significant differences in attention deficit, hyperactivity, and impulsivity between the two groups during the pre-test.

Table 3 compares the symptoms in both groups before and after the intervention. Both groups showed improvement (decreased mean scores) in hyperactivity, impulsivity, and attention deficit. The experimental group exhibited a greater improvement (larger mean difference) compared to the control group. Statistical analysis using paired t-tests revealed that the experimental group had significant progress in all three symptoms in the post-test. Similarly, the control group showed significant improvement in hyperactivity and attention deficit in the post-test compared to their pre-test scores. However, there was no significant improvement in impulsivity in the control group when comparing their pre-test and post-test scores.

Table 4 displays the post-test comparison between both groups. The experimental group demonstrated a significant improvement in attention deficit compared to the control group. However, our data did not reveal any statistically significant difference between the experimental and control groups for hyperactivity and impulsivity in the post-test. This suggests that while the application helped improve hyperactivity and impulsivity in the experimental group, there was no notable distinction compared to the control group.

4. Discussion

We developed a smartphone application for the sensory diet and found that mothers considered it highly useable and user-friendly (mean 8.35 out of 9). Our study also revealed that implementing the sensory diet application significantly improved hyperactivity, impulsivity, and attention deficit in children with ADHD in the experimental group. Specifically, the experimental group showed a significant improvement in attention deficit compared to the control group. These findings suggest that teaching mothers of children with ADHD about sensory diet exercises and providing a sensory diet schedule using a smartphone application can effectively enhance attention levels in children when compared to the control group.

These findings are consistent with Vanden Berg's study, which showed that the use of a weighted vest led to increased on-task behavior [37]. Similarly, Kim's study reported the positive effects of a home-based sensorimotor program on the executive and motor functions of children with ADHD [38]. Additionally, Jung [39] consistently found that integrated sensory-motor integration training reduced attention deficit in students with ADHD. Furthermore, Fedewa and Ervin [40] indicated that the use of stability balls improved attention and concentration in students with ADHD. Wu et al. [41], showed that therapy ball seats reduced attention deficit in children. Additionally, Sahoo et al. [11] investigated the effect of a sensory diet on the functional behaviors of children with ADHD and found that the use of a sensory diet increased functional behavior, indicating an improvement in attention. Previous studies on parent education, such as Lang et al. [42], and Fabiano et al. [43], have also demonstrated the effectiveness of this approach in reducing the symptoms of attention-deficit/hyperactivity disorder. Consistent with these findings, our study revealed a reduction in attention deficit in the experimental group when parents received training on implementing this treatment method through the application. Therefore, it can be concluded that training parents about this treatment approach using the application can contribute to

Table 1
Demographic data of children.

		Control	Experiment	*P*-value
		Number(percentage)	Number(percentage)	0.418
Age	5	3(50)	4(66.7)	
	6	2(33.3)	2(33.3)	
	7	1(16.7)	–	
Sex	Boy	5(83.3)	4(66.7)	0.549
	Girl	1(16.7)	2(33.3)	

Table 2
Results of the mean score of the experimental and control groups in the pretest.

Groups	Experimental	Control	T-value	Means difference	*P*-value (2_tailed)
	Mean ± SD	Mean ± SD			
Hyperactivity	10.5 ± 5.89	8.7 ± 4.36	0.612	1.8	0.555
Attention deficit	22 ± 6.13	23.83 ± 2.93	–	−1.83	0.937
Impulsivity	5.17 ± 2.32	4.17 ± 1.72	0.849	1	0.416

Man Whitney was applied for attention deficit.

Table 3
Comparison of experimental and control groups in post-test and pre-test[a].

Groups		Pre-test	Post-test	Means difference	T-value	*P*-value (2_tailed)
		Mean ± SD	Mean ± SD			
Control	Hyperactivity	8.7 ± 4.36	7 ± 3.22	−1.7	2.988	0.031
	Attention deficit	23.83 ± 2.93	20.5 ± 2.81	−3.33	5.42	0.003
	Impulsivity	4.17 ± 1.72	3.5 ± 1.76	−0.67	–	0.102
Experimental	Hyperactivity	10.5 ± 5.89	5.83 ± 3.82	−4.67	2.91	0.034
	Attention deficit	22 ± 6.13	13.67 ± 6.86	−8.33	8.43	<0.0001
	Impulsivity	5.17 ± 2.32	3.83 ± 1.32	−1.33	3.16	0.025

[a] Wilcoxon test was used to compare impulsivity in the control group. Paired sample T-test was used to compare pre and post-tests in other components.

Table 4
Comparison of the experimental and control groups in the post-test[a].

Groups	Experimental	Control	T-value	Means difference	P value
	Mean ± SD	Mean ± SD			
Attention deficit	13.67 ± 6.86	20.5 ± 2.81	−2.285	−6.83	0.048
Hyperactivity	5.83 ± 3.82	7 ± 3.22	−0.572	−1.16	0.580
Impulsivity	3.83 ± 1.33	3.5 ± 1.76	–	−0.33	0.937

[a] Mann-Whitney *U* test was used to compare impulsivity. An independent sample T-test was used to compare control and experimental tests in other components.

the reduction of attention deficit in children with ADHD.

Our post-test findings indicated a decrease in impulsivity and hyperactivity in the experimental group after the intervention; however, the difference compared to the control group was not statistically significant. Therefore, it can be concluded that solely teaching sensory diet activities to mothers of children with ADHD and providing a sensory diet schedule through the application may not lead to significant improvements in hyperactivity and impulsivity when compared to the control group. Jung [39] found a reduction in attention deficit after intervention in the experiment group, which is consistent with our results for the intervention group. However, unlike Jung's study, we did not observe a significant effect on impulsivity and hyperactivity compared to the control group. It is worth noting that both our intervention and control groups received routine occupational therapy in the clinic, which led to improvements in both groups compared to pre-intervention. This difference in findings may be attributed to the absence of a control group in Jung's study.

Some limitations should be considered. Firstly, our study had a small sample size, which limits the generalizability of the findings. Due to the small sample size in both groups and the fact that both groups received occupational therapy, no significant differences were found in terms of impulsivity and hyperactivity in the post-tests when compared to the control group. Additionally, we conducted this study as a feasibility study to provide preliminary insights for future research. As such, we did not perform a power calculation to determine the optimal sample size. Consequently, it is essential to replicate this study with a larger participant pool to obtain more

robust and reliable results.

In addition, our study focused specifically on preschool-aged children with ADHD. Therefore, the findings and conclusions may not be directly applicable or generalizable to older children or teenagers with ADHD. Hence, it is necessary to conduct a follow-up study with a larger number of participants to validate the findings. Additionally, the duration of app usage was limited to two months, suggesting that longer interventions may be required to assess the long-term effectiveness and sustainability of the application. Other evaluations to ensure the impact and safety of this application [44] are also required.

Moreover, it is important to note that our study did not gather any data regarding the sensory issues experienced by children. Therefore, it is recommended that future studies take into account this aspect. Although we made routine calls to parents in the experimental group to ensure appropriate usage of the app, we acknowledge that we did not collect data to compare treatment fidelity, which is an important aspect to consider in future research. Additionally, it is worth noting that in our study, the mothers who assessed the children were not blinded to the intervention. To enhance the validity of future studies, it would be beneficial to incorporate teacher-based evaluation tools as well. Lastly, it is recommended that future research focuses on developing this application in other languages and investigating the effects of this application or similar applications in different regions. This would allow for a broader understanding of its effectiveness and applicability across diverse populations.

In conclusion, this study successfully developed a useable smartphone application aimed at training parents of children with ADHD. The two-month usage of the application resulted in improvements in attention deficit within the experimental group, compared to the control group. These findings suggest that incorporating the use of a sensory diet application alongside other treatments may be an effective approach for reducing attention deficit experienced by children with ADHD. However, further research is needed to investigate the effect of this application on other symptoms of these children.

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Author contribution statement

Soraya Khanahmadi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Hossein Sourtiji: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Zohreh Khanahmadi: Conceived and designed the experiments; Performed the experiments.

Abbas Sheikhtaheri: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e19086.

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